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MONITORING SPATIOTEMPORAL AND MICRO-LEVEL CLIMATIC VARIATIONS IN LAHORE AND SUBRUBS USING SATELLITE IMAGERY AND MULTI-SOURCE DATA

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Abstract

This research is aimed at monitoring of spatio-temporal and micro-level climatic variations for the Lahore region from year 1950 to 2010. In order to accomplish the study objectives, multi-concept satellite imageries, meteorological data and anthropogenic parameters were analyzed in detail. A set of four imagery datasets, three from Landsat ETM+ and one from the ASTER, were digitally processed for major land cover features. Results of digital image-classification revealed prominent variations in various land cover features, specifically in terms of increased urbanization at the expense of oxygen-rich vegetal cover in the form of previously existing agriculture activity. The analysis of meteorological data for the said period indicates an increase of 2.0°C in the average minimum temperature and decrease of 0.6°C in the average maximum temperature of Lahore. The study proposes that rapidly increasing urbanization is causing a drastic increase in the emission of CO_2 and smog. The smog can be observed as dark-gray inversion layer underpinning greenhouse effect and causing increase in the minimum temperature and hence leads to the local climate change. Such effects are contributing towards the local climate change along with the increased urbanization, traffic density, de-vegetation and construction/ earth-moving practices. Resultantly, the use of remotely sensed imagery and multi-source data facilitates in estimating the spatiotemporal variations in the micro-level climate.

Keywords: Remote sensing, LANDSAT, ASTER, climate, de-vegetation, urbanization

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1. Introduction

The city flourished as a regional center under the Mughals in the seventeenth and early eighteenth centuries, but fell into decline in the ensuing hundred years until it was taken over by the British in the mid nineteenth century. Subsequently, the city became an important industrial and commercial center[1]. Consistent with the universal law of global urbanization, urbanization levels between 30% and 70% signifies tremendous development[2]. Throughout such periods, the necessary support of capital and inhabitants transport may significantly trim down the environmental relief ability and direct nonstop and tremendous load on the urban climate and environment [3, 4]. China is currently undergoing urbanization that is classified as accelerated development[5], it causes an increase in industrial as well as automobile exhaust creating a heat island.The current research correlates the spatial and temporal micro-level climatic variation occurred within the precincts of Lahore district due to rapid growth in urbanization. Located at $31^0$34´N and $74^0$22´E, the geographic extent of Lahore district has witnessed random and widespread growth in population from 0.67million to 6.3188million during 1941 to 1998[1]. This alarming growth rate has increased the population density from 379 to 3,566 persons/km^2[1] giving rise to congestion, environmental pollution, commuting problems, improper provisioning of civic services to the citizens, etc. Eighty two percent of the total population of Lahore district is urban and the remaining is rural [1]. Spatial variation is said to be variable across the difference that changes the soil type, habitat and the weather pattern[6] while temporal variations are those variations which are represented by weather in actual populations[7].

In the present study, remote sensing/geographic information system (RS/GIS) techniques including digitization and digital image classification and change detection have been exploited to estimate the increase in urbanization. Change detention (CD) is an important process in remote sensing applications[8,9]. In this process, four images, which are captured from the same scene but in different time instances, are given, and it aims at detecting the changes that occurred at that time interval. The output is a binary image (called change map), which represents the location of the occurring changes[10]. The emission of CO_2, smog (smoke+fog) formation and greenhouse effect are contributing an increase in the minimum temperature of Lahore.

1. Study area

Lahore is located on the left bank of the river Ravi, close to the border with India. The city's origins date back more than a thousand years. From a mud fort on the banks of the old Ravi and seat of the local Hindu rulers, it grew into a fortified city under the Afghans and Turks and spread beyond the walls to include a number of suburbs and gardens under the Mughals.

The climate of Lahore city is extreme. The summer season begins in April and remains till September. The weather is hottest in May and June. The respective mean maximum and minimum temperatures for these months are 45.4°C and 29.3°C respectively. The winter season remains from November till March. The coldest months are December, January and February. The mean maximum and minimum temperatures

for this phase are 21.1 °C and 7.2 °C respectively. There is light to moderate rainfall in the city during January and February. The temperature starts rising in April and the two next months are quite hot. The heat intensity is however reduced by occasional dust storms. The monsoon period starts from mid July and remains till mid September. The temperature creeps up to 48°C during May and June. The minimum temperature in winter sometimes reaches 1 °C. The average maximum and minimum temperature in Lahore are 30.8°C and 17.8°C respectively. The urbanization of Lahore started increasing since 1973 leading to an increase in temperature. Different human factors like housing schemes, industries, commercial areas development, deforestation and vehicles contributed to this increased temperature.

Table 1: Month-wise mean Meteorological values of study area.

Month	Mean Temperature (C)		Precipitation (mm)	Relative Humidity (%)
	Maximum	Minimum		
January	19.8	5.9	23.0	64.6
February	22.0	8.9	28.5	57.6
March	27.1	14.0	41.2	51.1
April	33.9	19.6	19.7	37.9
May	38.6	23.7	22.4	31.9
June	40.4	27.3	36.3	39.8
July	36.1	26.8	202.1	63.3
August	35.0	26.4	163.9	68.8
September	35.0	24.4	61.1	59.6
October	32.9	18.2	12.4	53.2
November	27.4	11.6	4.2	61.4
December	21.6	6.8	13.9	67.8
Annual	30.8	17.8	628.7	54.7

Source: *Pakistan Meteorological Department, Lahore*

The urbanization of Lahore is increasing rapidly. The fact is that people from rural areas come and settle in urban areas due to more job opportunities and high market rate [11]. De-vegetation resulted due to increased urban sprawl that led to an increase in the number of industries which is also a contributor to an increase in the temperature in turn.

2. Rapid growth of urbanization in Lahore

The population of Lahore city increased at a rapid rate of 4.35-4.51 percent during the inter-census period 1951-61, resulting in an increase of 52.65-67.36 percent in the registered individuals. Extensive influx of migrants during that period has been the major cause of the phenomenal increase However, the average annual growth rate of population decreased to 3.71 percent during 1972-81 and further declined to 3.32 percent during 1981-98[1]. It is likely that the decrease in growth rate during this period was due to the shifting of population to the city suburbs and hence, considered out of the city precincts. The overall increase in city population has been about six times during the last 47 years i.e. 1951-98[1].

Table 2: Population Statistics (1951-2006)

Census Year	Population (Millions)		Dist/Urban Ratio & (Urban %)	Inter-Census Increase (%)
	District	Urban		
1951	1.135	0.849	1.337 (75)	-
1961	1.625	1.296	1.254 (80)	69.846
1971	2.587	2.169	1.193 (83)	62.814
1981	3.545	2.953	1.200 (83)	72.976
1998	6.319	5.143	1.229 (81)	56.100
**2006	**8.295	**6.678	1.242 (81)	76.178
**Projected/ Estimated				

Source: Population Census 1998 and Urban Unit

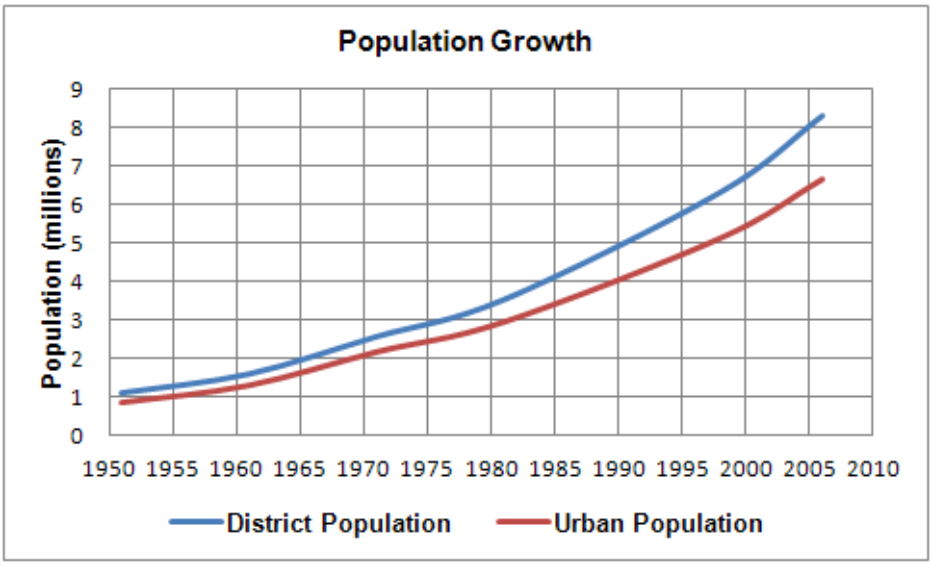

Figure 1: Graphical representation of the urban growth in study area.

As regards the population of Lahore Cantonment, it has increased from 245,474 in 1981 to 565,751 in 1998 resulting a registered higher Inter-census growth rate of 5.03 percent as compared to the Lahore Metropolitan Corporation, where the population increased from 2,707,215 (1981) to 4,577,744 (1998) at the average annual growth rate of 3.14 percent.

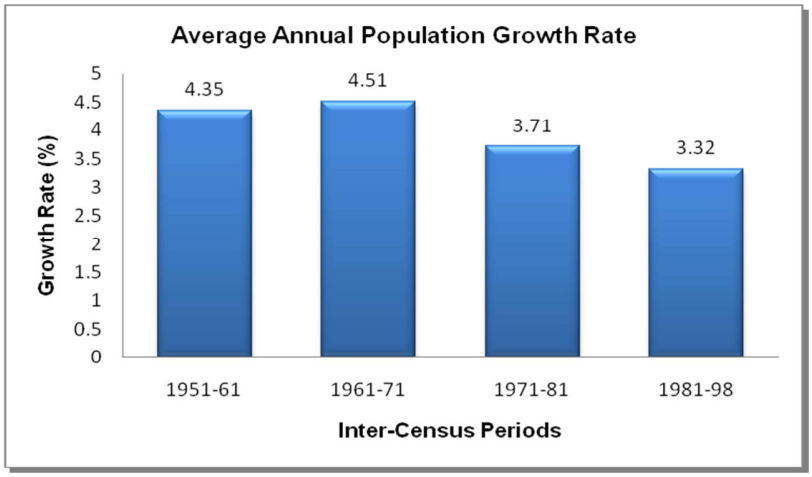

Figure 2: Averageannualpopulation growth rate – Lahore Cantt, (Source: Population Census 1998 and Urban Unit).

The average family size of Lahore city according to 1998 Census is 7.1 persons, which has slightly increased from 7.0 in 1981 which indicates slow construction rate compared with population increase during the inter-census period[1]. But during the1998 till 2007 the construction rate has increased against population.

Migration is a kind of geographical mobility between two geographical positions; generally it means a change of residence from the place of origin to the place of destination Migration data of 1998 Census shows movement of population from one to another district within the same province[1]. It does not cover persons who changed their place of residence within their own district. According to 1998 Census, the lifetime in-migrants in Lahore city are 897,129 that make 17.44 percent of the total population. The following table shows the percentage of migrants by reason of their migration.

Table 3: Migrant population by reason of migration source (all units are in percentage):Population(Census 1998 and Urban Unit)

Migrant Type	Study	Business	Employment	Returning	Health	Other Head	Transfer Home
Total	2.03	14.71	45.02	11.34	11.48	01.59	13.66
Male	2.96	01.91	26.49	19.94	20.34	01.97	16.92
Female	0.98	30.10	54.75	01.54	01.38	01.17	09.94

Housing is one of the basic needs of life. It gives shelter and facilities for maintenance of privacy, family health and standard living conditions. So the data on housing and facilities is necessary for planned development of the society. Now as consistent migration from rural to urban areas is going on in search of better jobs and living conditions an updated data on urban housing is required which will help to understand qualitative and quantitative aspects of living conditions of the people[1].

According to 1998 Census, there were 722,319 housing units in Lahore city compared to 441,721 given in 1980 Census that shows an increase of 63.52 % during the inter-census period(1981-98). Out of the total housing units 88.70% were in Metropolitan and 11.30 % in Cantonment area.

3. Data acquisition and processing

Digital classification of multi-temporal and multi-spectral imagery datasets reveals the results that support the stimulus behind conceiving the studies like the current one[1].The imagery datasets selected for the present research were of two different sensors acquired on four different dates spanning an interval of about 33 years. The dynamics of population expansion and its effects on the land cover features is obvious on the classified image datasets. Urbanization, the conversion of other types of land use associated with growth of populations and economy, is a main type of land use and land cover change in human history [1].The Landsat 7, Enhanced Thematic Mapper plus (ETM+) and Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data were used and standard deviation based supervised classification was performed over these datasets.

4. Results and discussions

The study revealed interesting results regarding average minimum and maximum temperatures of Lahore during the last 60 years. It was observed that Lahore's average minimum and maximum temperature (annual) during 60 years (1950-2010) was 18.44°C and 30.84°C respectively (Figs. 3 &4).

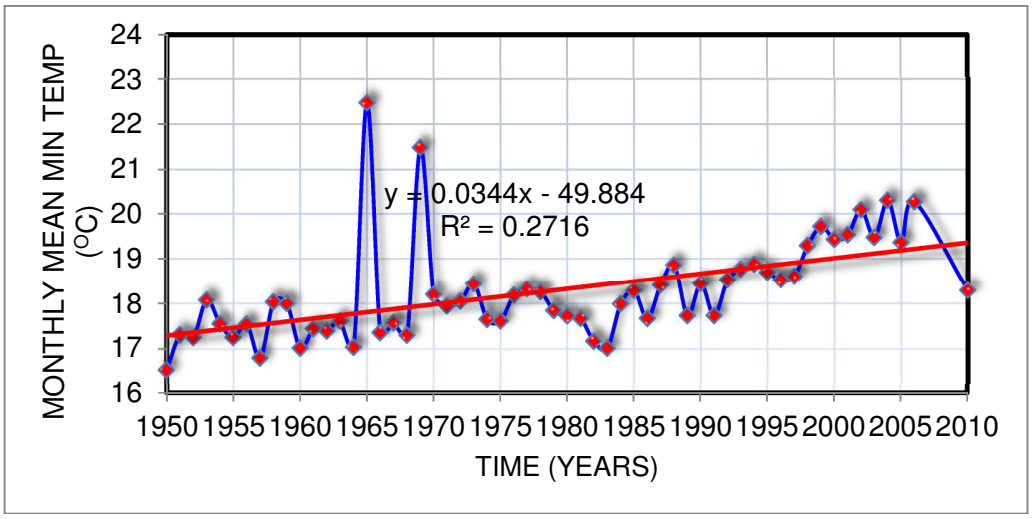

Figure 3: Annual mean minimum Temperature (C) 1950-2006.

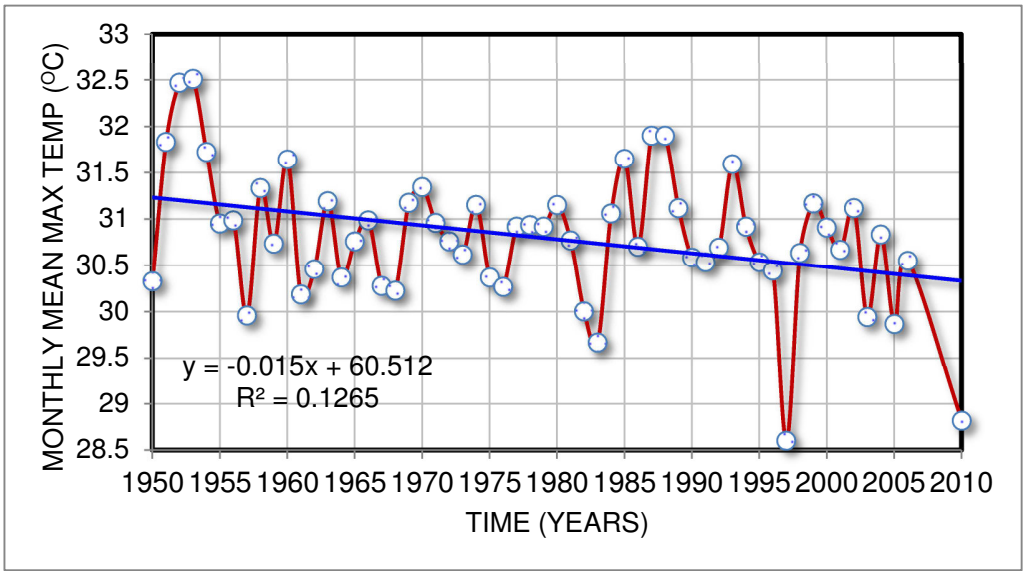

Figure 4: Annual mean maximum Temperature (C) 1950- 2006, computed from the Meteorological Data obtained from PMD, Lahore).

The increase in the nighttime temperature of Lahore has been a major source of its climate change. The urbanization has led to an increase of housing units, development of commercial areas, public places, and deforestation that has surely led to an increase in the overall temperature of Lahore. Buildings' construction material is mainly concrete that absorbs radiations during daytime and emits at night contributing to the increase in temperature. As the wind speed is less within the city, the heat radiations stay in the atmosphere and cause noticeable increase in the value of minimum temperature value.

The satellite images of Lahore taken from Landsat and Aster are for the years 1973, 1992, 2001 & 2006. Training areas for supervised classification were defined with the help of field-acquired data. Image classification is a process whereby all pixels in the image are categorized into a land cover class or theme.

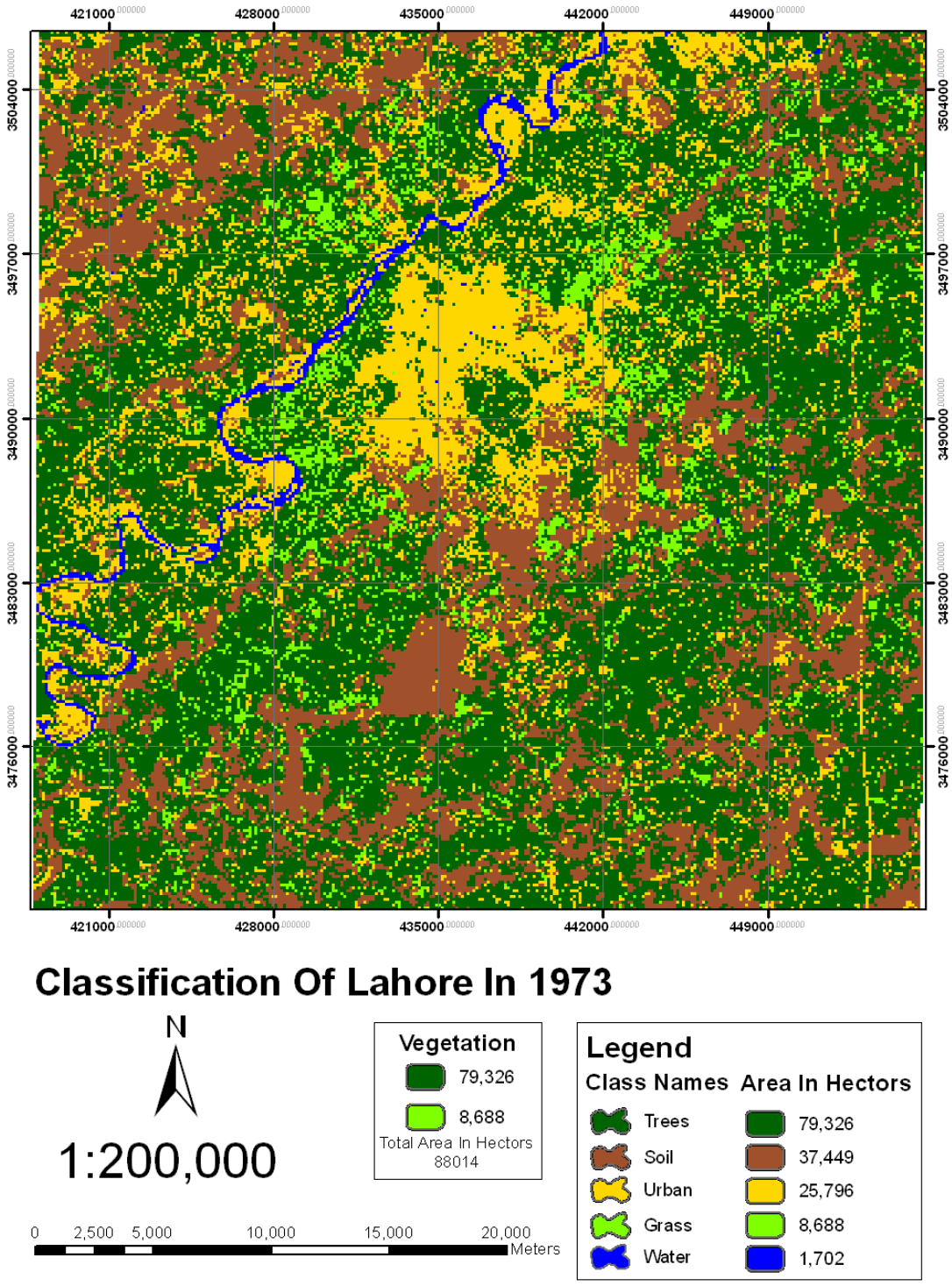

Figure 5:Multi-sensor image classification of land cover features of the study area. **(a)** Landsat classified image of Lahore (23-03-1973).

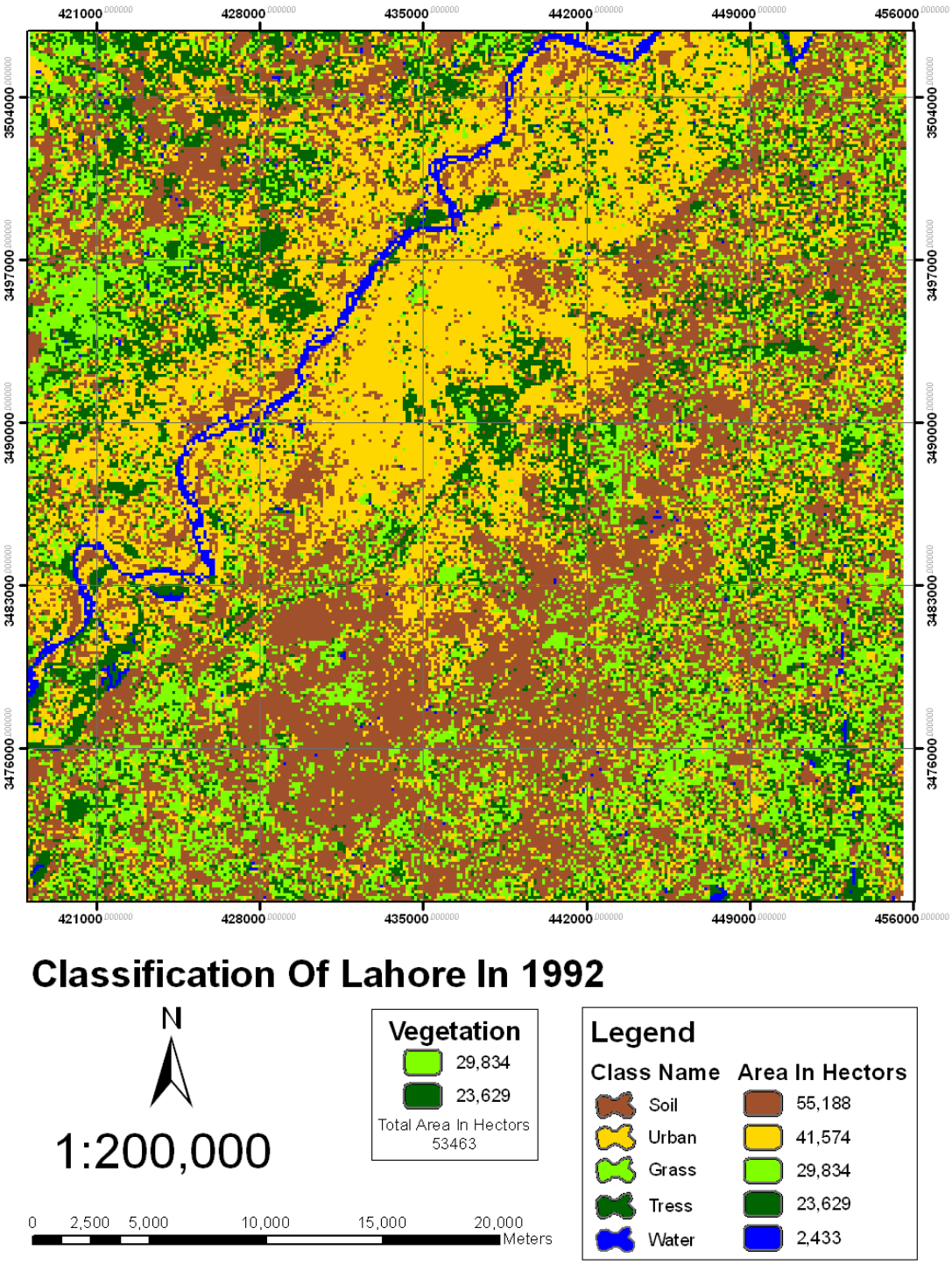

Figure 5(b): Landsat classified image of Lahore (15-10-1992).

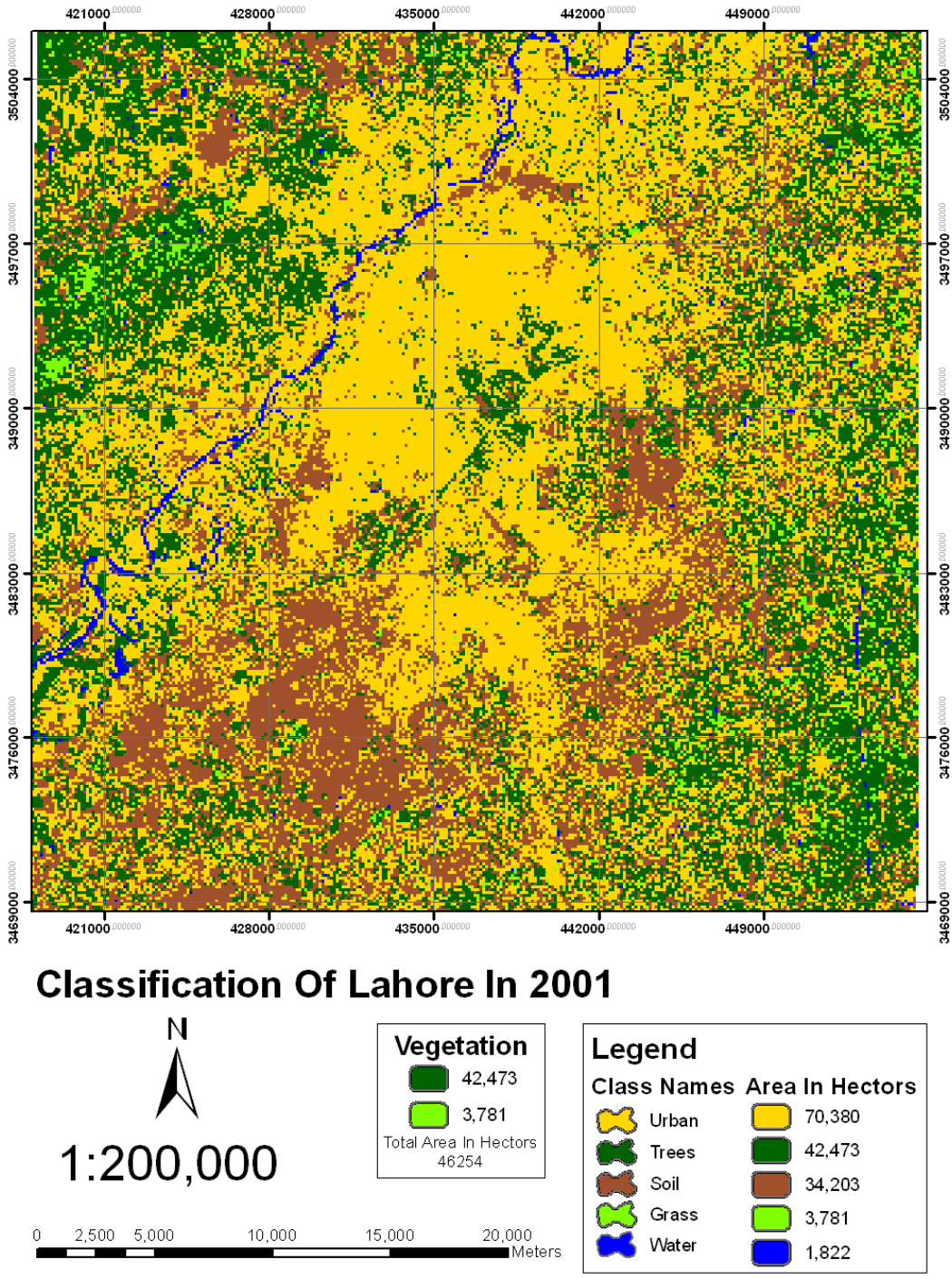

Figure 5(c): Landsat classified image of Lahore (30-09-2001).

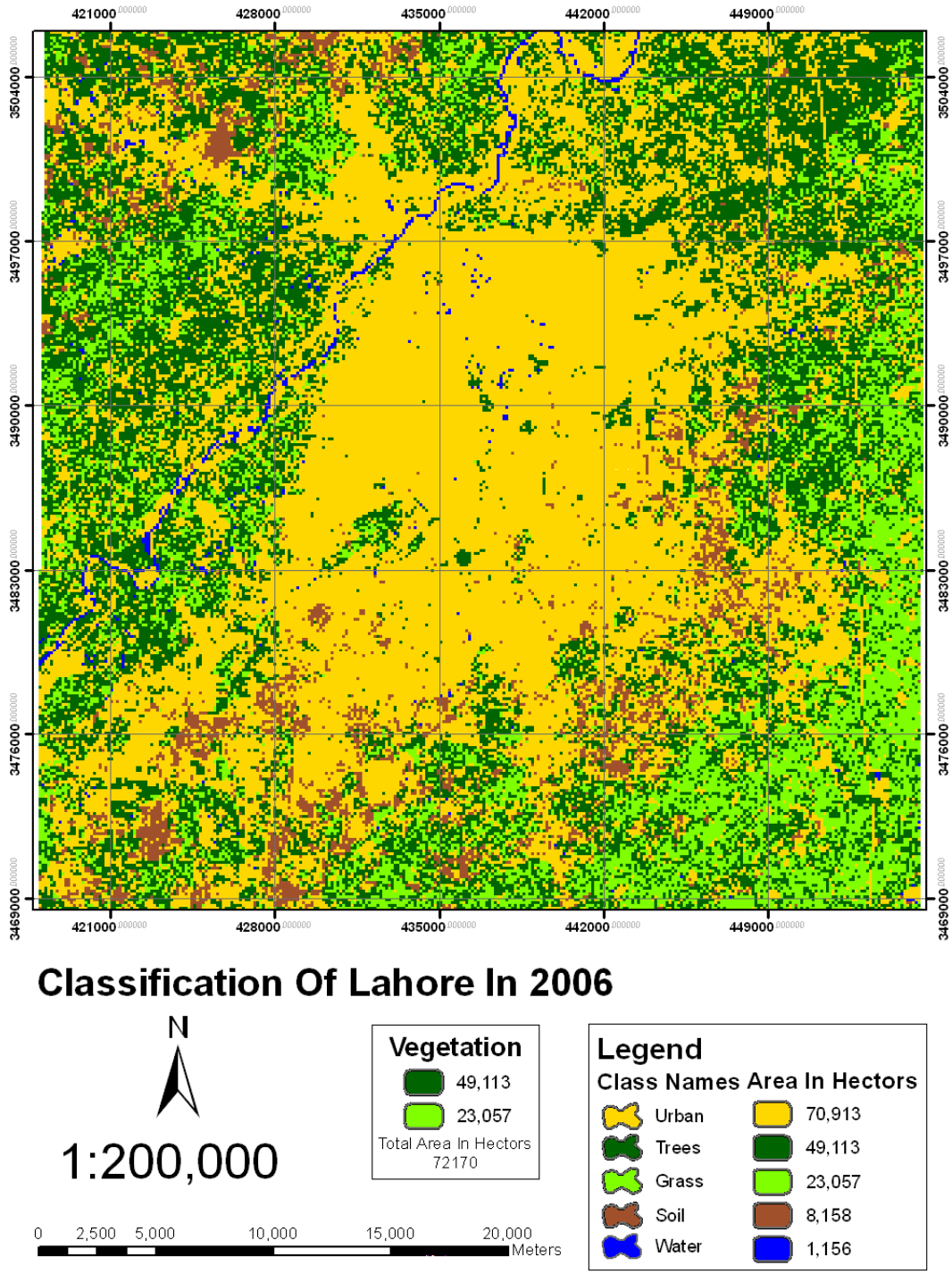

Figure 5(d): Aster classified image of Lahore (03-04-2006).

Spread of Urban Areas is quite clear as we see the results of Image-classified features from Year-1973 to 2006. Same way the vegetal cover is decreasing with bulging population. By observing the results it can be said that vegetation is receding away from the city center, as new settlements continue to eat-up the agricultural land.

Table 4: Results of Image Classification**.**

Image classification legend						
Sr.	Land-cover classes	Color	Area in hectares			
			Landsat MSS 23 Mar, 1973	Landsat TM 15 Oct, 1992	Landsat ETM 30 Sep, 2001	ASTER 03 Apr, 2006
a.	Urban regimes		25.796	41.574	70.380	70.913
b.	Vegetation (trees)		79.326	23.629	42.473	49.113
c.	Vegetation (grassland/ fields)		8.688	29.834	03.781	23.057
d.	Bare soil		25.796	55.188	34.203	08.158
e.	Water bodies		01.702	2.433	01.822	01.156

In addition to exploiting satellite imagery datasets, the alpha-numeric data comprising annual average temperature (maximum & minimum) were collected for the last 56 years from Pakistan Meteorological Department, Lahore. The purpose was to analyze the varying trend of temperature with changing land cover. Furthermore, vehicle data was used as another contributor to the climate change. Historic geographical Maps of the study area for the years, 1912, 1963 and 2006 were also studied and analyzed, using geospatial techniques, to monitor spread of populated regimes in the Lahore district over a period of a century. Study of a combination of imagery, map and alpha-numeric datasets has proved fairly useful for assessing the spatial and temporal variation in the climate of Lahore.

A significant factor that has affected the climate of Lahore is the increasing number of vehicle being registered per annum in the city. The data about registered vehicles in Lahore for the period of (1994 - June 2007) was collected from the Excise &Taxation Office, Government of the Punjab, Lahore. The graphical representation of the increasing trend in number of vehicles is given below:

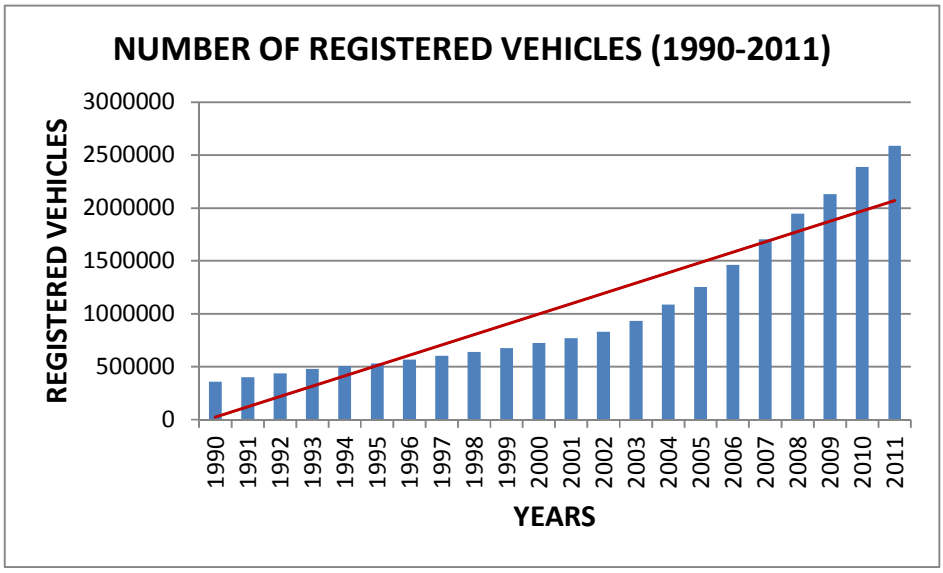

Figure 6: A Representation of increasing no. of vehicles/year – Lahore City (1990-2011)

Source: Excise and Taxation office, Lahore, Pakistan.

In order to further strengthening of the argument about contribution of increasing number of vehicles to cause change in the climate of the study area, a comparison has been made between the total number of vehicles registered during1994 to 2000 and 2001 to June 2007),which shows a difference of about 80,000 vehicles during that period. This number is quite significant when talking about an area of about 400sqkm that constitutes the Lahore City – the study area. The graphical representation of these figures is given below:

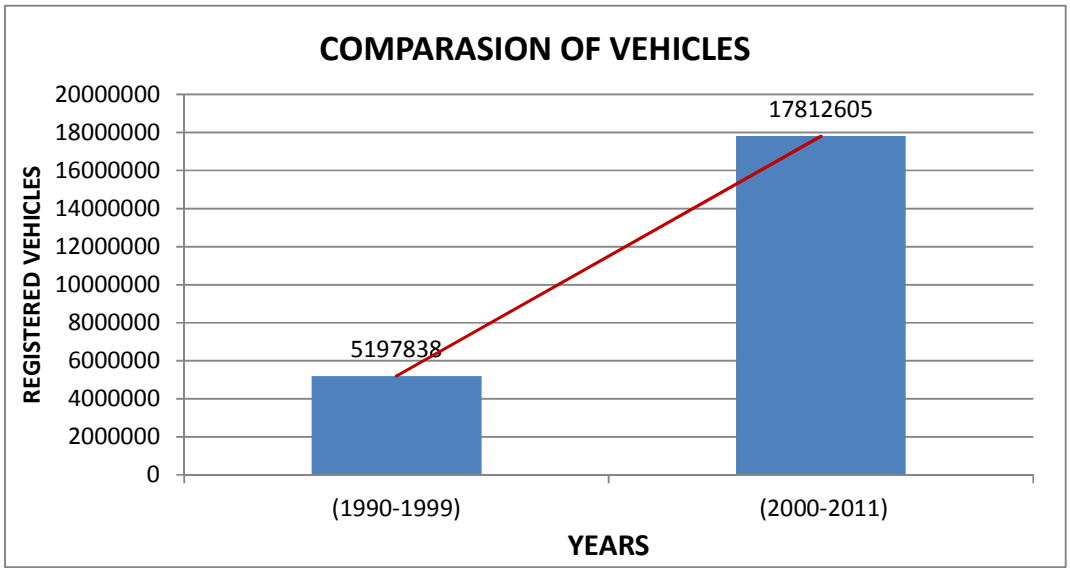

Figure 7: Graphical representation - Comparison of vehicles, Lahore City.

These vehicles are causing damaging effects on environment, an in turn on climate, by continuously releasing poisonous gases like carbon dioxide, carbon mono oxide, unburned gases and smoke in the air.

Conclusions

Based on the results of present research, it can be concluded that the rapid increase in urbanization has led to a drastic increase in emissions of CO_2 and formulation of smog, which appears as suspended-particulate-laden dense layer of cloud over the city area in Satellite Imageries. The cloud promotes trapping the reflected and emitted radiation from the Earth's surface and hence, creates Greenhouse effect. This effect becomes a cause of an increase in the minimum temperature of Lahore. Geographically, Lahore is located at 31°34' N latitude which comes in temperate zone (Low Latitude), where the temperature is much higher and the wind cannot cross freely as compared to the areas located in high latitude areas of the world. The city remains in perpetual twilight-like visibility during most of the winter, when rains are very scarce and the pollutants get held-up in the air. Furthermore, increasing shrinking extents of vegetal cover causes reduction in the amount of Oxygen and therefore, natural proportion of the amount of Oxygen is getting disturbed causing overall negative impact on the environment and also on the climate.

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